


Cosmochemistry and mineralogy of primitive meteorites
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FINAL REPORT

We have produced significant research results during the grant period. These have been reported in five papers published in *Geochimica et Cosmochimica Acta* and *Meteoritics and Planetary Science* and several others are in review. We also presented 17 abstracted talks at professional meetings. The citations are given in §2, and abstracts of the papers are provided in §3. The full papers are available on request.

1 Papers in refereed journals

Evidence that polycyclic aromatic hydrocarbons in two carbonaceous chondrites predate parent-body formation, F.L. Plows, J.E. Elsila, R.N. Zare, and P.R. Buseck, *Geochim. Cosmochim. Acta* **67**, 1429-1436, 2003.

Fine-grained rims in the Allan Hills 81002 and Lewis Cliff 90500 CM2 meteorites: Their origin and modification, X. Hua, J. Wang, and P.R. Buseck, *Meteoritics and Planetary Science* **37**, 229-244, 2002.

Opaque minerals in the matrix of the Bishunpur (LL3.1) chondrite: Constraints on the chondrule formation environment, D.S. Lauretta, P.R. Buseck, and T.J. Zega, *Geochim. Cosmochim. Acta* **65**, 1337-1353, 2001.

Mercury abundances and isotopic compositions in the Murchison (CM) and Allende (CV) carbonaceous chondrites, D.S. Lauretta, B. Klaue, J.D. Blum, and P.R. Buseck, *Geochim. Cosmochim. Acta* **65**, 2807-2818, 2001.

Mineralogy of fine-grained rims in the ALH 81002 CM chondrite, D.S. Lauretta, X. Hua, and P.R. Buseck, *Geochim. Cosmochim. Acta* **64**, 3263-3273, 2000.

2 Abstracts from professional meetings

Electron energy-loss spectroscopy (EELS) of Fe-bearing sheet silicates in CM Chondrites: LPSC, Houston, TX, (*Lunar Planet. Sci. Conf. XXXIV*, Abstr. #2089) T.J. Zega, L.A.J. Garvie, and P.R. Buseck, March, 2003.

- Sulfur-rich carbonaceous nanoglobules in the Tagish Lake meteorite: LPSC, Houston, TX, (*Lunar Planet. Sci. Conf. XXXIV*, Abstr. #2014) L.A.J. Garvie and P.R. Buseck, March, 2003.
- Nanometer-scale measurements of ferrous-ferric ratios in chondritic and terrestrial cronstedite: 18th Mtg. Internat'l. Min. Assn., Edinburgh, Scotland (*IMA Abstr.*, Abstr. TH6) T.J. Zega, L.A.J. Garvie, and P.R. Buseck, September 2002.
- Polycyclic aromatic hydrocarbons in two carbonaceous chondrites predate parent-body formation: 65th Ann. Mtg. Meteoritical Soc., UCLA (*Meteoritics & Planet. Sci.* 37, *Suppl.* A44) J.E. Elsila, F.L. Plows, R.N. Zare, and P.R. Buseck, July, 2002.
- Oscillatory zoning and aqueous alteration of fayalitic olivine from the LEW 90500 CM2 chondrite: 65th Ann. Mtg. Meteoritical Soc., Los Angeles, CA (*Meteoritics and Planetary Science, Suppl.*, submitted) X. Hua, J. Li, T.G. Sharp, and P.R. Buseck, July, 2002.
- Nanometer-scale measurements of ferrous-ferric ratios in chondritic cronstedite: LPSC, Houston, TX (*Lunar Planet. Sci. Conf. XXXIII*, Abstr. #2021) T.J. Zega, L.A.J. Garvie, and P.R. Buseck, March, 2002 (CD-ROM).
- Origin of polycyclic aromatic hydrocarbons in carbonaceous chondrites: 224th Am. Chem. Soc. Natl. Mtg., Boston, MA (*Abstrs.*, *ACS 224*, 010-PHYS Part 2) R.N. Zare, F. Plows, J. Elsila, and P.R. Buseck, August, 2002.
- Fine-grained rim mineralogy of the Cold Bokkeveld CM chondrite by transmission electron microscopy: 64th Ann. Mtg. Meteoritical Soc., Rome, Italy (*Meteoritics and Planetary Science* 36, *Suppl.*, A230-A231) T.J. Zega and P.R. Buseck, September, 2001.
- Opaque minerals and the origin of Bishunpur (LL3.1) fine-grained chondrule rims: 64th Ann. Mtg. Meteoritical Soc., Rome, Italy (*Meteoritics and Planetary Science* 36, *Suppl.*, A110) D.S. Lauretta and P.R. Buseck, September, 2001.
- An experimental investigation of Fe-Si alloy corrosion in the solar nebula: LPSC, Houston, TX (*Lunar Planet. Sci. Conf. XXXII*, Abstr. #2165) T.J. Zega, D.S. Lauretta, and P.R. Buseck, March, 2001 (CD-ROM).
- Si-isotopic fractionation in silicate minerals from chondritic meteorites: A possible new probe for early solar system processes: LPSC, Houston, TX (*Lunar Planet. Sci. Conf. XXXII*, Abstr. #1852) X. Hua, J. Wang, G.R. Huss, T.G. Sharp, and P.R. Buseck, March, 2001 (CD-ROM).
- Thermal analysis of labile trace elements in CM and CV carbonaceous chondrites using inductively coupled plasma-mass spectrometry: LPSC, Houston, TX (*Lunar Planet. Sci. Conf. XXXII*, Abstr. #1356) D.S. Lauretta, B. Klaue, J.D. Blum, and P.R. Buseck, March 2001 (CD-ROM).
- Troilite-silicate-metal inclusions and rims in the Bishunpur LL3.1 chondrite: Products of impact-induced mobilization on a primitive asteroid: LPSC, Houston, TX (*Lunar Planet. Sci. Conf. XXXII*, Abstr. #1250) T. Kojima, D.S. Lauretta, and P.R. Buseck, March, 2001 (CD-ROM).
- Inductively coupled plasma mass spectrometry measurements of bulk mercury abundances and isotopic ratios in Murchison (CM) and Allende (CV): 63rd Ann. Mtg. Meteoritical Soc., Chicago, IL (*Meteoritics* 35, *Suppl.*, A95-A96) D.S. Lauretta, B. Klaue, J.D. Blum, and P.R. Buseck, August, 2000.

A high-resolution transmission electron microscope study of fine-grained phosphates in metal from the Bishunpur LL3.1 ordinary chondrite: 63rd Ann. Mtg. Meteoritical Soc., Chicago, IL (*Meteoritics and Planetary Science* 35, *Suppl.*, A84) C.L. Johnson, D.S. Lauretta, and P.R. Buseck, August, 2000.

Mineralogy of a fine-grained rim within the cold Bokkeveld CM chondrite: A transmission electron microscope study: 63rd Ann. Mtg. Meteoritical Soc., Chicago, IL (*Meteoritics and Planetary Science* 35, *Suppl.*, A177) T.J. Zega and P.R. Buseck, August, 2000.

Silicon-isotopic abundances in silicate minerals from the Kaba and Mokoia CV3 carbonaceous chondrites: 63rd Ann. Mtg. Meteoritical Soc., Chicago, IL (*Meteoritics and Planetary Science* 35, *Suppl.*, A-78) X. Hua, J. Wang, and P.R. Buseck, August, 2000.

3 Abstracts of papers in refereed journals

Evidence that polycyclic aromatic hydrocarbons in two carbonaceous chondrites predate parent-body formation, F.L. Plows, J.E. Elsila, R.N. Zare, and P.R. Buseck, *Geochim. Cosmochim. Acta* 67, 1429-1436, 2003.

Organic material in meteorites provides insight into the cosmochemistry of the early solar system. The distribution of polycyclic aromatic hydrocarbons (PAHs) in the Allende and Murchison carbonaceous chondrites was investigated using spatially resolved microprobe laser-desorption laser-ionization mass spectrometry. Sharp chemical gradients of PAHs are associated with specific meteorite features. The ratios of various PAH intensities relative to the smallest PAH, naphthalene, are nearly constant across the sample. These findings suggest a common origin for PAHs dating prior to or contemporary with the formation of the parent body, consistent with proposed interstellar formation mechanisms.

Fine-grained rims in the Allan Hills 81002 and Lewis Cliff 90500 CM2 meteorites: Their origin and modification, X. Hua, J. Wang, and P.R. Buseck, *Meteoritics and Planetary Science* 37, 229-244, 2002.

Antarctic CM meteorites Allan Hills (ALH) 81002 and Lewis Cliff (LEW) 90500 contain abundant fine-grained rims (FGRs) that surround a variety of coarse-grained objects. FGRs from both meteorites have similar compositions and petrographic features, independent of their enclosed objects. The FGRs are chemically homogeneous at the 10 μ m scale for major and minor elements and at the 25 μ m scale for trace elements. They display accretionary features and contain large amounts of volatiles, presumably water. They are depleted in Ca, Mn, and S but enriched in P. All FGRs show a slightly fractionated rare earth element (REE) pattern, with enrichments of Gd and Yb and depletion of Er. Gd is twice as abundant as Er.

Our results indicate that those FGRs are not genetically related to their enclosed cores. They were sampled from a reservoir of homogeneously mixed dust, prior to accretion to their parent body. The rim materials subsequently experienced aqueous alteration under identical conditions. Based on their mineral, textural, and especially chemical similarities, we conclude that ALH 81002 and LEW 90500 likely have a similar or identical source.

Opaque minerals in the matrix of the Bishunpur (LL3.1) chondrite: Constraints on the chondrule formation environment, D.S. Lauretta, P.R. Buseck, and T.J. Zega, *Geochim. Cosmochim. Acta* 65, 1337-1353, 2001.

The chemistry and mineralogy of a group of opaque mineral assemblages in the matrix of the Bishunpur LL3.1 ordinary chondrite provide insight into the nebular environment in which they formed. The assemblages consist of a kamacite (Fe,Ni) core that is rimmed by troilite (FeS) and fayalite (Fe₂SiO₄). Accessory phases in the rims include silica (SiO₂), chromite (FeCr₂O₄), whitlockite (Ca₃(PO₄)₂), maricite (FeNaPO₄), magnetite (Fe₃O₄), and tetrataenite (FeNi). We suggest that the metal melted in and equilibrated with an igneous chondrule under high-temperature, reducing conditions. In this environment the molten alloys incorporated varied amounts of Si, Ni, P, Cr, and Co, depending on the oxygen fugacity and temperature of the melt. Some of the metal was subsequently expelled from the chondrule interiors into the surrounding nebular gas. As the temperature dropped, the alloy solidified and volatile elements corroded the metal. The main reaction products were troilite and fayalite. Thermodynamic equilibrium calculations are used to constrain the conditions under which these two phases can form simultaneously in the solar nebula. Kinetic factors are used to place a lower limit on the formation temperature. We determine that the metal corroded between 1173 and 1261 K at a total pressure in the range of 1025.0 to 1024.1 bars and a dust/gas ratio of 302 to 355 x relative to solar composition. These conditions are consistent with our model that the metal corroded in a dust-rich region of the solar nebula that was cooling after a chondrule formation event.

Mercury abundances and isotopic compositions in the Murchison (CM) and Allende (CV) carbonaceous chondrites, D.S. Lauretta, B. Klaue, J.D. Blum, and P.R. Buseck, *Geochim. Cosmochim. Acta* **65**, 2807-2818, 2001.

The abundance and isotopic composition of Hg was determined in bulk samples of both the Murchison (CM) and Allende (CV) carbonaceous chondrites using single- and multi-collector inductively coupled plasma mass spectrometry (ICP-MS). The bulk abundances of Hg are 294 ± 15 ng/g in Murchison and 30.0 ± 1.5 ng/g in Allende. These values are within the range of previous measurements of bulk Hg abundances by neutron activation analysis (NAA). Prior studies suggested that both meteorites contain isotopically anomalous Hg, with δ^{196/202}Hg values for the anomalous, thermal-release components from bulk samples ranging from 2260 ‰ to 1440 ‰ in Murchison and from 2620 ‰ to 1540 ‰ in Allende (Jovanovic and Reed, 1976a; 1976b; Kumar and Goel, 1992). Our multi-collector ICP-MS measurements suggest that the relative abundances of all seven stable Hg isotopes in both meteorites are identical to terrestrial values within 0.2 to 0.5 ‰.

On-line thermal-release experiments were performed by coupling a programmable oven with the single-collector ICP-MS. Powdered aliquots of each meteorite were linearly heated from room temperature to 900°C over twenty-five minutes under an Ar atmosphere to measure the isotopic composition of Hg released from the meteorites as a function of temperature. In separate experiments, the release profiles of S and Se were determined simultaneously with Hg to constrain the Hg distribution within the meteorites and to evaluate the possibility of Se interferences in previous NAA studies. The Hg-release patterns differ between Allende and Murchison. The Hg-release profile for Allende contains two distinct peaks, at 225° and 343°C, whereas the profile for Murchison has only one peak, at 344°C. No isotopically anomalous Hg was detected in the thermal-release experiments at a precision level of 5 to 30 ‰, depending on the isotope ratio. In both meteorites the Hg peak at ~340°C correlates with a peak in the S-release profile. This correlation suggests that Hg is associated with S-bearing phases and, thus, that HgS is a major Hg-bearing phase in both meteorites. The Hg peak at 225°C for Allende is similar to release patterns of physically adsorbed Hg on silicate and metal grains. Prior studies suggested

that the isotopic anomalies reported from NAA resulted from interference between ^{203}Hg and ^{75}Se . However, the amount of Se released from both meteorites, relative to Hg, is insufficient to produce all of the observed anomalies.

Mineralogy of fine-grained rims in the ALH 81002 CM chondrite, D.S. Lauretta, X. Hua, and P.R. Buseck, *Geochim. Cosmochim. Acta* **64**, 3263-3273, 2000.

The mineralogy of fine-grained rims in ALH 81002, a relatively primitive CM carbonaceous chondrite, has been determined by using transmission electron microscopy. The most abundant phase is Mg-rich serpentine, which occurs in small (#20 nm) crystals with cylindrical or fibrous morphologies. Cronstedtite, an Fe-rich phyllosilicate, occurs as relatively large (100 to 2500 nm), platy crystals. Some cronstedtite is coherently intergrown with tochilinite. In many cases, cronstedtite has been partially altered to serpentine. The compositions and textures of these two phases provide a mineralogical and morphologic alteration sequence that parallels the known compositional trend for CM chondrite matrix. Accessory minerals embedded within the phyllosilicates include chlorite, pentlandite, gypsum, olivine, kamacite, taenite, and chromite. Regions containing only anhydrous minerals also occur. The hydrated and anhydrous regions are in direct contact with each other, suggesting that the rims accreted material from multiple reservoirs.